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PHOTOVOLTAIC ARRAY SPACE POWER PLUS DIAGNOSTICS EXPERIMENT

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Abstract: The objective of the Photovoltaic Array Space Power Plus Diagnostics (PASP Plus) experiment is to measure the effects of the interaction of the low- to mid-altitude space environment on the performance of a diverse set of small solar-cell arrays (planar and concentrator, representative of present and future military technologies) under differing conditions of velocity-vector orientation and simulated (by biasing) high-voltage operation. Solar arrays to be tested include Si and GaAs planar arrays and several types of GaAs concentrator arrays. Diagnostics (a Langmuir probe and a pressure gauge) and a transient pulse monitor (to measure radiated and conducted EMI during arcing) will be used to determine the impact of the environment on array operation to help verify various interactions models. Direction of the effort is by AFSTC's Geophysics Lab and WRDC's Aero Propulsion and Power Lab, with Jet Propulsion Lab (JPL) as the experiment development contractor. Presently, JPL is finishing the assembly and testing of a brassboard unit; fabrication of a PASP Plus flight unit awaits the finding of a suitable spaceflight vehicle. Results from a successful PASP Plus flight will furnish answers to important interactions questions and provide inputs for design and test standards for photovoltaic space-power subsystems.

INTRODUCTION

Air Force mission requirements in the 1990s will necessitate larger, higher powered space systems. In supplying electrical power for such systems, consideration must be given to operating photovoltaic subsystems at higher voltage levels to reduce cable weight (minimize I^2R losses). New solar-cell materials are being investigated for higher efficiency. To make solar arrays less vulnerable to laser attack, various configurations are being investigated for "concentrator" arrays, which accept incoming energy from only a narrow angle around array boresight. These new technology innovations lead to new environmental interactions problems. To avoid launching space-power subsystems with built-in failure modes, environmental interactions questions must be answered before operational subsystems are built.

In 1985, AFSTC's Geophysics Laboratory (GL) and WRDC's Aero Propulsion and Power Laboratory (PO), through a Memorandum of Agreement, initiated the Photovoltaic Array Space Power (PASP) experiment development effort, with Jet Propulsion Laboratory (JPL) as the development contractor. Originally, PASP was to be one of several engineering technology experiments for GL's Interactions Measurement Payload for Shuttle (IMPS). However, after the Challenger loss, circumstances dictated that, instead of the full IMPS, we develop (and attempt to obtain spaceflights for) individual engineering technology experiments. After adding the necessary space-environment diagnostic sensors to PASP (these were originally part of IMPS), the experiment became PASP plus diagnostics, or PASP Plus for short.

PASP PLUS INSTRUMENTATION

The PASP Plus experiment consists of a set of solar-cell array modules, associated array-performance measurement equipment, and environmental diagnostic sensors.

PASP Plus can accommodate up to six solar array modules. At present we have four on hand; these are:

a. a silicon planar array [to be used as a standard] (see Figure 1).

b. an advanced-technology gallium-arsenide planar array (see Figure 2).

c. a mini-Cassegrainian concentrator array having eight small Cassegrainian-reflector structures (see Figure 3). The GaAs solar cell is located at the center of the base of the reflector surface. Two-dimensional concentration is achieved.

d. a SLATS (semi-parabolic low-aperture trough system) concentrator array, resembling Venetian blinds (see Figure 4). The concave curvature of a slat reflects incoming light onto a line of solar cells on the back surface of an adjacent slat. For SLATS, only one-axis concentration is achieved.

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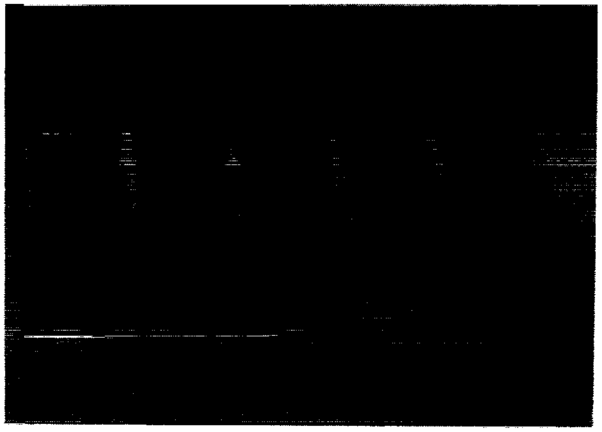

Figure 1. PASP Plus Silicon Planar Array Module.

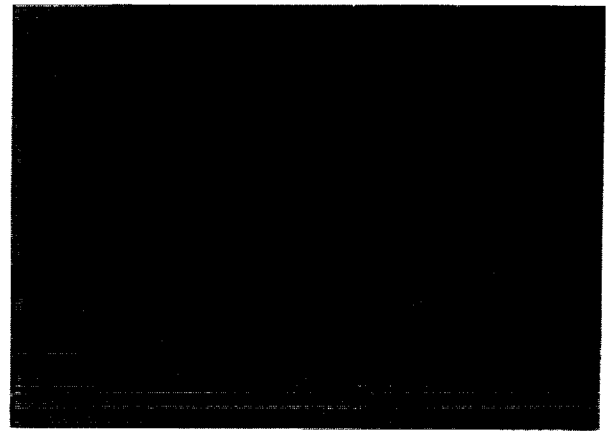

Figure 2. PASP Plus GaAs Planar Array Module.

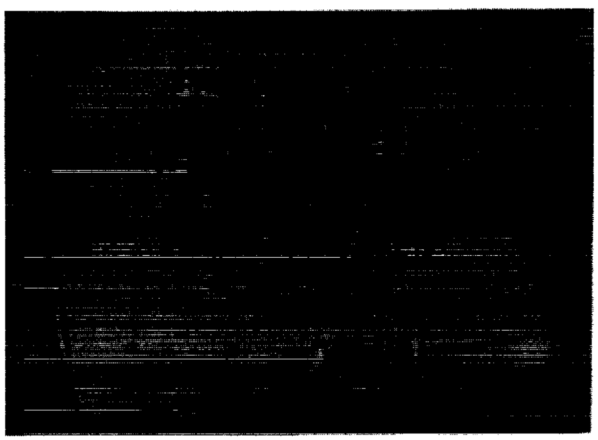

Figure 3. PASP Plus Mini-Cassegrainian Concentrator Array Module.

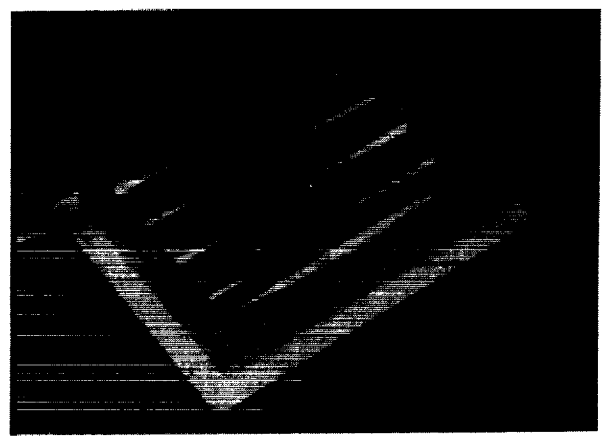

Figure 4. PASP Plus SLATS Concentrator Array Module.

Instrumentation to measure array performance includes:

a. a sun incidence-angle sensor to measure the alignment of the array modules to the incident solar energy. This sensor is especially important for the concentrator arrays, which have only about a two-degree acceptable operating range around solar boresight. If no other means of sun-pointing is available on the carrier, the crossed-axes outputs from the sun incidence-angle sensor could be used to provide pointing information to the carrier.

b. direct current and voltage meters for I-V curve measurements.

c. temperature sensors on each array module, so array performance can be correlated with operating temperature.

d. electrical transient sensors (E-field for detection of radiated EMI and current-loop for detection of power-line EMI) connected to a transient pulse monitor (TPM) which will obtain the characteristics (amplitude, rise time, pulses per time period) of arc-discharge pulses that will occur during high-voltage biasing of the arrays.

Environmental diagnostic sensors of PASP plus include:

a. a pressure gauge to measure ambient pressures surrounding the arrays.

b. a Langmuir probe to measure low-energy plasma parameters (density and temperature).

Other functional assemblies include:

a. a multi-step high-voltage generator for biasing the arrays.

b. a buffer storage for intermediate data handling.

c. a controller network to control biasing and measurement sequences.

PASP PLUS OPERATIONS

The data gathering format for PASP Plus features a programmed sequence of measurements, with careful notation of ambient pressure [from pressure gauge], charged-particle density [from Langmuir probe], array temperature, array orientation toward the sun [from sun incidence-angle sensor], and array orientation with respect to vehicle velocity vector (ram, wake, in-between).

In a sequence for a given array, the current-voltage (I-V curves) measurements are made first. The high-voltage biasing operation follows next in the sequence. (The Langmuir probe is disconnected for the bias measurements.) Simulated high-voltage operation will be obtained utilizing eleven biasing steps from -500 to +500 Volts from the multi-step biasing generator. The particular values of biasing must be chosen beforehand (increments of ~25 V are available). Using preprogrammed bias values, PASP Plus progresses through the programmed sequence. The biasing is applied to one side of the array; each bias level will remain applied for 20 seconds. The 20-sec interval is chosen to have sufficient time to reach steady-state conditions (in the first few seconds) and still have enough time left in the interval to make statistically meaningful measurement of arc-discharge parameters (particularly, the number of arcs in the interval) with the TPM.

HIGH-VOLTAGE INTERACTIONS

Greater spacecraft power requirements bring about a need for higher-voltage power-distribution subsystems. Enhanced interactions between the space plasma and the arrays operating at higher voltages must be experimentally investigated in a systematic manner for different types of arrays. PASP Plus provides the means for accomplishing this task.

Based on the extensive work of the group at the NASA Lewis Research Center, important insights into high-voltage interactions in a space plasma (Ref. 1,2) have been obtained through both laboratory and flight test results (Ref. 3,4,5). Explanations concerning the arcing of negatively biased solar arrays have been put forth by Jongeward and Parks (Ref. 6,7); they suggest that arcing is initiated as a result of ion neutralization and associated charge buildup on a thin insulating layer over the metallic interconnects.

If one terminus of an array is operated at a high negative voltage (by biasing in the case of PASP Plus), the negatively biased part of the array will, beyond a certain voltage level, start to experience arcing. The arc discharges could damage the array (especially around the interconnects area) and generate unwanted electromagnetic interference that could cause false signals or even trigger erroneous commands.

If one terminus of an array is operated at a high positive voltage, the positively biased part will experience enhanced electron current collection. For an operational solar array, this effect would result in the loss of photovoltaicly generated power in the form of "leakage" current, diminishing the electrical power available to the spacecraft for useful (mission oriented) purposes.

For positive biasing, there is additional problem. If a high positive bias is applied to one terminus of an array, the array will achieve a potential distribution with respect to the space plasma so as to equalize the positive and negative currents to the array surface from the space plasma. Since the electron current density will be much greater than the ion current density, the positively biased terminus will float somewhat positive while the opposite terminus will float substantially negative (surface <u>areas</u> will balance current <u>densities</u>). The opposite terminus (negative with respect to the space plasma) will then be susceptible to arcing problems discussed above for negatively biased arrays. If the solar array makes up most of the surface area of the spacecraft and the opposite terminus of the array is connected to the frame of the spacecraft (i.e., grounded), then not only the opposite end of the array but also other parts of the spacecraft could become susceptible to arcing.

One way of preventing swinging the vehicle (or the other terminus of the array) negative when applying positive bias is to turn on an electron emitter (e.g., a tungsten filament). The outgoing electron current produced will balance the incoming electron current to the positively biased part to the array without the radical altering of vehicle potentials (with respect to the space plasma) cited in the previous paragraph. PASP Plus has incorporated the use (and non-use) of an electron-emitting filament in its high-voltage biasing operations.

The wide altering of vehicle potentials when biasing one array terminus highly positive occurs for large dielectric (i.e.,planar) arrays. For concentrators (mini-Cassegrainian or SLATS), the principal reception area is not the solar-cell surface but a metalized reflecting area (which may be covered by a thin protective dialectric coating). Hence, for concentrators there may or may not be any wide altering of vehicle potentials when a large positive voltage is applied (or generated) at one terminus of an array. There might be no need (or utility) in employing an electron emitter to prevent wide vehicle potential swings. Since PASP Plus has both planar and concentrator arrays, this difference in interaction effects can be appropriately investigated by the PASP Plus experiment.

EXPERIMENT STATUS

The Preliminary Design Review (PDR) for the PASP experiment was held in January 1986 and the Critical Design Review (CDR) in June 1987. Following the Jan 1988 annual review of PASP, the Geophysics Laboratory (after finalizing the breakup of the IMPS payload) made the decision to incorporate PASP-relevant sensors from IMPS. Work on the new PASP Plus experiment went forward at JPL with the pressure gauge, Langmuir probe, and TPM supplied as GFE (Government Furnished Equipment), as were the four array modules supplied by the Aero Propulsion and Power Laboratory. Since no firm spaceflight for PASP Plus has been identified, there was no reason or basis (interface information) to fabricate an actual PASP Plus flight unit. GL decided to conclude JPL's present effort with a brassboard demonstration model of PASP Plus with full working electrical configuration but not mechanical flight configuration. Completion of the fabrication and testing of the PASP Plus brassboard unit is expected in September 1989. The GFE items are considered to be flight hardware. Examples of fabricated circuit boards for the ASIS (array selection and instrumentation system) and DACS (data acquisition and control system) portions of PASP Plus are shown in Figures 5 and 6.

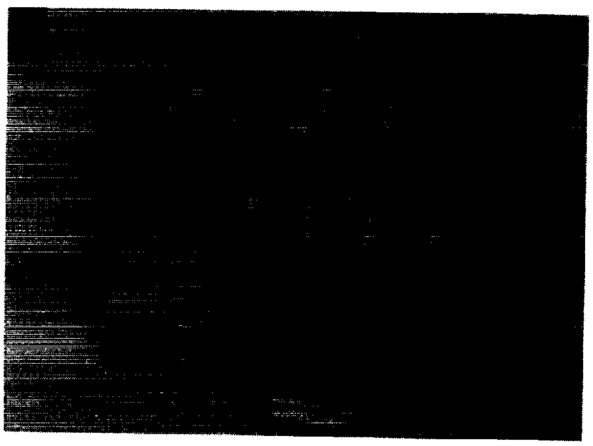

Figure 5. PASP Plus ASIS I-V Curve Subsystem Board.

Figure 6. PASP Plus DACS Thermal Detector Controller Board.

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EXPECTED RESULTS FROM PASP PLUS

Because of the complex characteristics of the space-plasma environment, the interaction effects on new-technology solar arrays cannot be calculated or convincingly simulated in ground tests. Results from a successful PASP Plus experiment will facilitate the fielding of new photovoltaic technologies through the validating and upgrading of computer models, development of CAE tools, and enhancement of ground-based simulation and testing.

We hope that arrangements can be made for a flight of the PASP Plus experiment in the reasonably near future (FY91-92). If PASP Plus achieves such a ride, we expect that the results will be thoroughly analyzed, both from an array performance viewpoint and an interaction phenomenology view-point. The performance of each of the planar and concentrator arrays will be measured at the various bias levels and under various space-plamsa environment conditions (ram, wake or in-between orientation; passage through an auroral region if a high-inclination ride is obtained). Increases in radiated and power-line noise during high-voltage biasing will be measured. Short-term or long-term changes in array performance will be correleted with environmental condition changes determined by the diagnostic sensors. From all the data, we will try to ascertain cause-and-effect relationships.

Within the first year after a successful flight, the Geophysics Lab and the Aero Propulsion and Power Lab will conduct a series of workshops at which correleted PASP Plus data would be made available to the space-power and space-systems communities (in DoD and NASA). The workshops will be targeted to key topics such as concentrator performance, high-voltage operation, EMI-generation effects. Reports on these key topics resulting from these workshops will be directed towards upgrading relevant space-power design guidelines and test standards.

CONCLUSIONS

The PASP Plus complement of different types of solar arrays and diagnostic (interactions and environment measuring) sensors has been chosen to address the environmental sensitivities of the new technologies being developed. Failure to determine the extent of interaction problems by experiments such as PASP Plus could lead to serious flaws in future space-power subsystems.

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